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United States Environmental Protection Agency

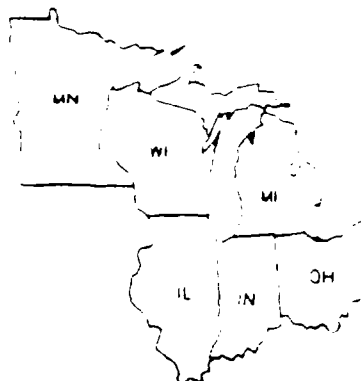
Region V

77 West Jackson Boulevard
Chicago, Illinois 60604

Superfund Division

Facsimile Cover Sheet
Telephone Number

312-353-5541



To:

Cheryl Jovett / Dave

Office phone:

Machine No: (618) 692-7022

From:

Brad Bradley

Office phone:

(312) 886-4742

Mail code:

Date:

11/1/99

Number of pages,
including cover:

10

Message:

Enclosed are some bases for why rototilling is not a good alternative for remediating lead-contaminated soils. The first two letters outline why Region 10 rejected rototilling as a remedial alternative, and the last four pages are part of a publication of technology alternatives for soils remediation for 5 metals, including lead. On the fourth page, note that rototilling is excluded from the list of alternatives and is, thus, not considered an acceptable alternative. Rototilling was studied by the responsible parties at the NL Industries Site - Granite City, Illinois. Rototilling was not successful because adequate mixing could not be achieved. They never gave EPA a copy of this report since it did not prove their case for rototilling. EPA strongly recommends excavation of soils rather than tilling. Brad

Bechtel

50 Beale Street
San Francisco, CA 94105-1895
Mailing address: P.O. Box 193965
San Francisco, CA 94119-3965

November 16, 1990

Ms. Mary Kay Voytilla
Work Assignment Manager
U.S. Environmental Protection Agency
Region 10, Superfund Branch
1200 6th Avenue
Seattle, WA 98101

Subject: ARCSWEST Contract No. 68-W3 0060
Work Assignment 60-03-01F3
Ruston/N. Tacoma RI/IS
Proposed Omission of Tilling and Discing From FS

Dear Mary Kay:

As you requested, we have evaluated further our rationale for omitting Tilling and Discing from detailed evaluation. Our rationale was previously summarized as four items in our October 17, 1990, memorandum and is expanded below. A fifth reason for omitting tilling and discing has also been described below.

1. CERCLA Objectives - Tilling and discing as a separate technology does not meet any of the three CERCLA objectives of reducing mobility, volume, and toxicity of contaminants.

Mobility and toxicity at the Ruston site are largely related to the transportation of soil particles to which contaminants have adhered. The use of tilling to reduce mobility and subsequent toxicity could be enhanced by using common agents or binders such as portland cement, lime kiln dust, or a lime/fly ash mixture. However, the use of these agents is essentially identical to stabilization/solidification technology which was determined in Letter Report 1 to be inappropriate for in-situ remediation of residential areas. The resulting hardened soil would be incompatible with existing landscaping and vegetation growth.

The use of tilling to provide in-situ mixing of the reagents currently under consideration for the soil washing treatability study would not be applicable to the Ruston site. The addition of these reagents would increase the mobility of soil contaminants. It would be impractical to contain or recover the contaminated wash solutions.

The reduction in volume of contaminants is discussed below in Item 2.



Bechtel Environmental, Inc.

Ms. Mary Kay Voytilla

Proposed Omission of Tilling and Discing

November 16, 1990

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2. Potential Increase in Volume - Mixing contaminated surface soil with uncontaminated subsurface soil may result in a more uniform distribution of contaminants and may decrease contaminant concentrations in potential hot spots. However, on a mass balance, the amount of contaminants would not be decreased. Additionally, tilling could potentially increase the total volume of soil with arsenic concentration above a specified action/clean-up level by mixing contaminants into previously uncontaminated or less contaminated soils.

To illustrate, assume the action/clean-up level is 150 ppm and the arsenic profile is 420 ppm, 100 ppm, and 80 ppm for surface, 6 inch and 12 inch depths, respectively. Before tilling and discing, only the top 6 inches of soil would be above the action/clean-up level. After tilling and discing, the entire 12 inches of soil could be above the action/clean-up level since the average soil concentration would be approximately 200 ppm in the top 12 inches. By tilling and discing to 12 inches the volume of contaminated soil above the action/clean-up level may have doubled.

3. Reduction in Contaminant Concentration - Tilling and discing is only effective in reducing surface contaminant concentrations if the underlying soils are lower in concentration. Soil data at the site is limited to a depth of 12 inches. As we have discussed in our October 19 memorandum to you, recent soil data indicate that arsenic contamination is still present at a depth of 12 inches and is highly variable in concentration, similar to the high variation observed at the surface and 6 inch depth. At shallow depths of 6 inches and 12 inches it was determined that subsurface concentrations exceed surface concentrations approximately 26% of the time. The profile of contamination below the 12 inch depth cannot be predicted with any significant degree of confidence. Thus, a reduction in contaminant concentration resulting from tilling at depths greater than 12 inches cannot be demonstrated.

The effective tilling depth has not yet been determined. However, it has been determined from operating experience at a local landfarm that the maximum depth for deep tilling is approximately three feet. In addition, the recommended tilling depth for common root crops is two feet. While these depths may be achievable, the tractor required for deep tilling is generally a D-8 Caterpillar or similar, which would be unwieldy at most locations in a residential area. The depth to utilities such as power, water, sewer lines and other hazards would have to be determined prior to deep tilling. For tighter areas, a common garden rototiller could be used, but the effective tilling depth would be limited to approximately one foot.

Ms. Mary Kay Voytilla

Proposed Omission of Tilling and Discing

November 16, 1990

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4. ROD Review - Our review of all Federal ROD summaries from 1982 through 1989 and the EPA ROD system database did not reveal any precedent for the use of tilling and discing to mix contaminated surface soils with less contaminated subsurface soils. The review also included the 17 ROD abstracts which you previously transmitted to us. When included in selected remedies, tilling is commonly used either in-situ or on stockpiled soil to provide aeration of volatile organic compounds or to enhance microbiological activity during bioremediation of organics.

At the Byron Johnson Salvage, Illinois, site the selected remedy included tilling to provide adequate in-situ mixing after the addition of reagents for cyanide reduction. However, as discussed in Item 1 above, mixing of reagents is not applicable to the Ruston site.

Alternative technologies evaluated as part of the Anaconda Smelter/Mill Creek, Montana, RI/FS included deep tilling of contaminated surface soil. The pilot study has been requested for additional information. Four tilling techniques were evaluated, resulting in surface soil metals reduction between 30% and 86%, which was not adequate to reduce exposure risks to acceptable levels. Reductions in concentration at that site, however, would be largely dependent on the concentration profile present, which is site specific. Profile comparisons between Ruston and Mill Creek cannot be made without pilot study data.

In addition to RODs, the EPA-sponsored Alternative Treatment Technology Information Center (ATTIC) database was searched for information on the use of tilling and discing as a remedial alternative. No information was referenced by ATTIC.

5. Similarities With Sodding Alternative - Another alternative being evaluated in the draft FS is the containment of contaminated soil using sodding. As part of our detailed evaluation of this alternative, sodding was determined to require tilling for surface soil preparation. Some clean fill and supplemental soil amendments would be required. Similarly, for the tilling and discing alternative, some clean fill, supplemental soil amendments and revegetation, such as sod, would likely be required. Thus, the actual differences between the sodding and tilling and discing alternatives are minimal. Since EPA policy and guidance for an FS is to evaluate a range of distinctly different alternatives, we recommend that tilling be deleted as a separate alternative because it is so similar to the sodding and capping alternative.

We believe that sufficient justification remains to discontinue our evaluation of tilling and discing. Please let us know if you concur with the elimination of tilling and discing from the screening of technologies section of the FS.

Ms. Mary Kay Voytilla
Proposed Omission of Tilling and Discing
November 16, 1990
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Please do not hesitate to call Dale Obenauer at (415) 768-0891 or me at (415) 768-7256 if you have any questions or comments.

Sincerely,

A handwritten signature in cursive script, reading "Greg R. Haskins".

Greg Haskins
Project Manager

GH:DO:sfj

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Bechtel

50 Beale Street
San Francisco, CA 94105-1895

Mailing address: P.O. Box 193965
San Francisco, CA 94119-3965

October 17, 1990

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SUPERFUND BRANCH

Ms. Mary Kay Voytilla
Work Assignment Manager
U.S. Environmental Protection Agency
Region 10, Superfund Branch
1200 6th Avenue
Seattle, WA 98101

Subject: Proposed Omission of Tilling and Discing
ARCSWEST Contract No. 68-W9-0060
Work Assignment 60-03-OLF3
Ruston/N. Tacoma RI/FS

Dear Mary Kay:

As we discussed earlier, the Feasibility Study document being prepared for the Ruston/North Tacoma Superfund Site is a "living" document in the sense that the approach it presents can and will undergo changes throughout the preparation process. It has recently been determined that sufficient information exists to propose the omission of tilling and discing from further detailed evaluation. The rationale for this omission can be summarized as four items:

- Tilling and discing does not meet any of the three CERCLA objectives (i.e., reducing the mobility, volume and toxicity of contaminants).
- Tilling and discing has the potential to increase the volume of contaminated soil (by mixing contaminated soil with uncontaminated soil).
- Tilling and discing is only effective in reducing surface contaminant concentrations if the underlying soils are lower in concentration. Recent soil analysis data indicate approximately half of the surface soil at the site is underlain by material containing higher contaminant concentrations.
- Our review of remedial actions that have been selected at other Superfund sites has not revealed any precedent for the use of tilling and discing.

We believe that the items listed above are sufficient justification to discontinue our evaluation of tilling and discing. Please let us know if you concur with our rationale. We would then revise the screening of technologies section of the FS to reflect elimination of tilling and discing.

Please do not hesitate to call me at (415) 768-7256 if you have any questions or comments.

Sincerely,



Greg Haskins
Project Manager



R:sfj

Bechtel Environmental, Inc.



Engineering Bulletin

Technology Alternatives for the Remediation of Soils Contaminated with As, Cd, Cr, Hg, and Pb

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the U.S. Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practical" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element." The *EPA Engineering Bulletins* are a series of documents that summarize the available information on selected treatment and site remediation technologies and related issues. They provide summaries and references of the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their hazardous waste sites. Documents that describe individual site remediation technologies focus on remedial investigation scoping needs. Addenda are issued periodically to update the original bulletins.

Introduction

This bulletin provides remedial project managers, on-scene coordinators, and other state or private remediation managers and their technical support personnel with information to facilitate the selection of appropriate remedial alternatives for soil contaminated with arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb). This bulletin primarily condenses information that is included in a more comprehensive Technical Resource Document (TRD) entitled "Contaminants and Remedial Options at Selected Metal-Contaminated Sites [1]".

Common compounds, transport, and fate are discussed for each of the five elements. A general description of metal-con-

taminated Superfund soils is provided. The technologies covered are immobilization [containment (caps, vertical barriers, horizontal barriers), solidification/stabilization (cement-based, polymer microencapsulation), and vitrification]; and separation and concentration (soil washing, pyrometallurgy, and soil flushing). Use of treatment trains is also addressed.

Electrokinetics is addressed in the technical resource document, but not here, since it had not been demonstrated at full scale in the U.S. for metals remediation. Also, an update on the status of in situ electrokinetics for remediation of metal-contaminated soil is in progress and should be available in the near fu-

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ture [2]. Another change from the original technical resource document is that physical separation is addressed in the bulletin under soil washing, whereas it was previously covered as a separate topic.

It is assumed that users of this bulletin will, as necessary, familiarize themselves with (1) the applicable or relevant and appropriate regulations pertinent to the site of interest; (2) applicable health and safety regulations and practices relevant to the metals and compounds discussed; and (3) relevant sampling, analysis, and data interpretation methods. The majority of the information on which this bulletin is based was collected during 1992 to 1994. Information on Pb battery (Pb, As), wood preserving (As, Cr), pesticide (Pb, As, Hg), and mining sites is limited, as it was in the original technical resource document. Most of these site types have been addressed in other EPA Superfund documents [3][4][5][6][7][8]. The greatest emphasis is on remediation of inorganic forms of the metals of interest. Organometallic compounds, organic-metal mixtures, and multimetal mixtures are briefly addressed.

At the time of this printing, treatment standards for Resource Conservation and Recovery Act (RCRA) wastes that contain metals (in 40 CFR 268) and for contaminated media (in 40 CFR 269) are being investigated for potential revisions. These revisions may impact the selection of the technology for remediating sites containing these metal-bearing wastes.

Overview of As, Cd, Cr, Hg, and Pb and Their Compounds

This section provides a brief, qualitative overview of the physical characteristics and mineral origins of the five metals, and factors affecting their mobility. More comprehensive and quantitative reviews of the behavior of these five metals in soil can be found in other readily available EPA Superfund documents [1][9][10].

Overview of Physical Characteristics and Mineral Origins

As is a semimetallic element or metalloid that has several allotropic forms. The most stable allotrope is a silver-gray, brittle, crystalline solid that tarnishes in air. As compounds, mainly As_2O_3 , can be recovered as a by-product of processing complex ores mined mainly for copper, Pb, zinc, gold, and silver. As occurs in a wide variety of mineral forms, including arsenopyrite ($FeAsS_4$), which is the main commercial ore of As worldwide.

Cd is a bluish-white, soft, ductile metal. Pure Cd compounds rarely are found in nature, although occurrences of greenockite (CdS) and otavite ($CdCO_3$) are known. The main sources of Cd are sulfide ores of Pb, zinc, and copper. Cd is recovered as a by-product when these ores are processed.

Cr is a lustrous, silver-gray metal. It is one of the less common elements in the earth's crust, and occurs only in compounds. The chief commercial source of Cr is the mineral chromite ($FeCr_2O_4$). Cr is mined as a primary product and is not recovered as a by-product of any other mining operation. There are no chromite ore reserves, nor is there primary production of chromite in the U.S..

Hg is a silvery, liquid metal. The primary source of Hg is cinnabar (HgS), a sulfide ore. In a few cases, Hg occurs as the principal ore product; it is more commonly obtained as the by-product of processing complex ores that contain mixed sulfides, oxides, and chloride minerals (these are usually associated with

base and precious metals, particularly gold). Native or metallic Hg is found in very small quantities in some ore sites. The current demand for Hg is met by secondary production (i.e., recycling and recovery).

Pb is a bluish-white, silvery, or gray metal that is highly lustrous when freshly cut but tarnishes when exposed to air. It is very soft and malleable, has a high density (11.35 g/cm^3) and low melting point (327.4°C), and can be cast, rolled, and extruded. The most important Pb ore is galena (PbS). Recovery of Pb from the ore typically involves grinding, flotation, roasting, and smelting. Less common forms of the mineral are cerussite ($PbCO_3$), anglesite ($PbSO_4$), and crocoite ($PbCrO_4$).

Overview of Behavior of As, Cd, Cr, Pb, and Hg

Since metals cannot be destroyed, remediation of metal-contaminated soil consists primarily of manipulating (i.e., exploiting, increasing, decreasing, or maintaining) the mobility of metal contaminant(s) to produce a treated soil that has an acceptable total or leachable metal content. Metal mobility depends upon numerous factors. As noted in reference [9]:

"Metal mobility in soil-waste systems is determined by the type and quantity of soil surfaces present, the concentration of metal of interest, the concentration and type of competing ions and complexing ligands, both organic and inorganic, pH, and redox status. Generalization can only serve as rough guides of the expected behavior of metals in such systems. Use of literature or laboratory data that do not mimic the specific site soil and waste system will not be adequate to describe or predict the behavior of the metal. Data must be site specific. Long term effects must also be considered. As organic constituents of the waste matrix degrade, or as pH or redox conditions change, either through natural processes of weathering or human manipulation, the potential mobility of the metal will change as soil conditions change."

Based on the above description of the number and type of factors affecting metal mobility, it is clear that a comprehensive and quantitative description of mobility of the five metals under all conditions is well beyond the scope of this bulletin. Thus, the behavior of the five metals are described below, but for a limited number of conditions.

Cd, Cr (III), and Pb are present in cationic forms under natural environmental conditions [9]. These cationic metals generally are not mobile in the environment and tend to remain relatively close to the point of initial deposition. The capacity of soil to adsorb cationic metals increases with increasing pH, cation exchange capacity, and organic carbon content. Under the neutral to basic conditions typical of most soils, cationic metals are strongly adsorbed on the clay fraction of soils and can be adsorbed by hydrous oxides of iron, aluminum, or manganese present in soil minerals. Cationic metals will precipitate as hydroxides, carbonates, or phosphates. In acidic, sandy soils, the cationic metals are more mobile. Under conditions that are atypical of natural soils (e.g., pH <5 or >9 ; elevated concentrations of oxidizers or reducers; high concentrations of soluble organic or inorganic complexing or colloidal substances), but may be encountered as a result of waste disposal or remedial processes, the mobility of these metals may be substantially increased. Also, competitive adsorption between various metals has been observed in experiments involving various solids with oxide surfaces ($\gamma\text{-FeOOH}$, $\alpha\text{-SiO}_2$, and $\gamma\text{-Al}_2\text{O}_3$). In several experiments, Cd adsorption was decreased by the addition of Pb or Cu for all three of these sol-

ids. The addition of zinc resulted in the greatest decrease of Cd adsorption. Competition for surface sites occurred when only a few percent of all surface sites were occupied [11].

As, Cr (VI), and Hg behaviors differ considerably from Cd, Cr (III), and Pb. As and Cr(VI) typically exist in anionic forms under environmental conditions. Hg, although it is a cationic metal, has unusual properties (e.g., liquid at room temperature, easily transforms among several possible valence states).

In most As-contaminated sites, As appears as As_2O_3 or as anionic As species leached from As_2O_3 , oxidized to As (V), and then sorbed onto iron-bearing minerals in the soil. As may be present also in organometallic forms, such as methylarsenic acid ($\text{H}_2\text{AsO}_2\text{CH}_3$) and dimethylarsenic acid ($(\text{CH}_3)_2\text{AsO}_2\text{H}$), which are active ingredients in many pesticides, as well as the volatile compounds arsine (AsH_3) and its methyl derivatives [i.e., dimethylarsine ($\text{HAs}(\text{CH}_3)_2$) and trimethylarsine ($\text{As}(\text{CH}_3)_3$)]. These As forms illustrate the various oxidation states that As commonly exhibits (-III, 0, III, and V) and the resulting complexity of its chemistry in the environment.

As (V) is less mobile (and less toxic) than As (III). As (V) exhibits anionic behavior in the presence of water, and hence its aqueous solubility increases with increasing pH, and it does not complex or precipitate with other anions. As(V) can form low solubility metal arsenates. Calcium arsenate ($\text{Ca}_3(\text{AsO}_4)_2$) is the most stable metal arsenate in well-oxidized and alkaline environments, but it is unstable in acidic environments. Even under initially oxidizing and alkaline conditions, absorption of CO_2 from the air will result in formation of CaCO_3 and release of arsenate. In sodic soils, sufficient sodium is available, such that the mobile compound Na_2AsO_4 can form. The slightly less stable manganese arsenate ($\text{Mn}_2(\text{AsO}_4)_2$) forms in both acidic and alkaline environments, while iron arsenate is stable under acidic soil conditions. In aerobic environments, H_2AsO_4 predominates at pH < 2 and is replaced by H_2AsO_4^- , HASO_4^{2-} and AsO_4^{3-} as pH increases to about 2, 7, and 11.5, respectively. Under mildly reducing conditions, H_2AsO_3 is a predominant species at low pH, but is replaced by H_2AsO_3^- , HASO_3^{2-} , and AsO_3^{3-} as pH increases. Under still more reducing conditions and in the presence of sulfide, As_2S_3 can form. As_2S_3 is a low-solubility, stable solid. AsS_2^- and AsS_4^{3-} are thermodynamically unstable with respect to As_2S_3 [12]. Under extreme reducing conditions, elemental As and volatile arsine (AsH_3) can occur. Just as competition between cationic metals affects mobility in soil, competition between anionic species (chromate, arsenate, phosphate, sulfate, etc.) affects anionic fixation processes and may increase mobility.

The most common valence states of Cr in the earth's surface and near-surface environment are +3 (trivalent or Cr(III)) and +6 (hexavalent or Cr(VI)). The trivalent Cr (discussed above) is the most thermodynamically stable form under common environmental conditions. Except in leather tanning, industrial applications of Cr generally use the Cr(VI) form. Due to kinetic limitations, Cr (VI) does not always readily reduce to Cr (III) and can remain present over an extended period of time.

Cr (VI) is present as the chromate (CrO_4^{2-}) or dichromate ($\text{Cr}_2\text{O}_7^{2-}$) anion, depending on pH and concentration. Cr (VI) anions are less likely to be adsorbed to solid surfaces than Cr (III). Most solids in soils carry negative charges that inhibit Cr (VI) adsorption. Although clays have high capacity to adsorb cationic metals, they interact little with Cr (VI) because of the similar charges carried by the anion and clay in the common pH range of soil and groundwater. The only common soil solid that adsorbs Cr(VI) is iron oxyhydroxide. Generally, a major

portion of Cr(VI) and other anions adsorbed in soils can be attributed to the presence of iron oxyhydroxide. The quantity of Cr(VI) adsorbed onto the iron solids increases with decreasing pH.

At metal-contaminated sites, Hg can be present in mercuric form (Hg^{2+}) mercurous form (Hg_2^{2+}), elemental form (Hg^0), or alkylated form (e.g., methyl and ethyl Hg). Hg_2^{2+} and Hg^{2+} are more stable under oxidizing conditions. Under mildly reducing conditions, both organically bound Hg and inorganic Hg compounds can convert to elemental Hg, which then can be readily converted to methyl or ethyl Hg by biotic and abiotic processes. Methyl and ethyl Hg are mobile and toxic forms.

Hg is moderately mobile, regardless of the soil. Both the mercurous and mercuric cations are adsorbed by clay minerals, oxides, and organic matter. Adsorption of cationic forms of Hg increases with increasing pH. Mercurous and mercuric Hg also are immobilized by forming various precipitates. Mercurous Hg precipitates with chloride, phosphate, carbonate, and hydroxide. At concentrations of Hg commonly found in soil, only the phosphate precipitate is stable. In alkaline soils, mercuric Hg precipitates with carbonate and hydroxide to form a stable (but not exceptionally insoluble) solid phase. At lower pH and high chloride concentration, soluble HgCl_2 is formed. Mercuric Hg also forms complexes with soluble organic matter, chlorides, and hydroxides that may contribute to its mobility [9]. In strong reducing conditions, HgS , a very low solubility compound is formed.

General Description of Superfund Soils Contaminated with As, Cd, Cr, Hg, and Pb

Soils can become contaminated with metals from direct contact with industrial plant waste discharges; fugitive emissions; or leachate from waste piles, landfills, or sludge deposits. The specific type of metal contaminant expected at a particular Superfund site would obviously be directly related to the type of operation that had occurred there. Table 1 lists the types of operations that are directly associated with each of the five metal contaminants.

Wastes at CERCLA sites are frequently heterogeneous on a macro and micro scale. The contaminant concentration and the physical and chemical forms of the contaminant and matrix usually are complex and variable. Of these, waste disposal sites collect the widest variety of waste types; therefore concentration profiles vary by orders of magnitude through a pit or pile. Limited volumes of high-concentration "hot spots" may develop due to variations in the historical waste disposal patterns or local transport mechanisms. Similar radical variations frequently occur on the particle-size scale as well. The waste often consists of a physical mixture of very different solids, for example, paint chips in spent abrasive.

Industrial processes may result in a variety of solid metal-bearing waste materials, including slags, fumes, mold sand, fly ash, abrasive wastes, spent catalysts, spent activated carbon, and refractory bricks [13]. These process solids may be found above ground as waste piles or below ground in landfills. Solid-phase wastes can be dispersed by well-intended but poorly controlled reuse projects. Waste piles can be exposed to natural disasters or accidents causing further dispersion.

Soil Cleanup Goals for As, Cd, Cr, Hg, and Pb

Table 2 provides an overview of cleanup goals (actual and potential) for both total and leachable metals. Based on inspec-

Table 1. Principal Sources of As, Cd, Cr, Hg, and Pb Contaminated Soils

Contaminant	Principal Sources
As	Wood preserving As-waste disposal Pesticide production and application Mining
Cd	Plating Ni-Cd battery manufacturing Cd-waste disposal
Cr	Plating Textile manufacturing Leather tanning Pigment manufacturing Wood preserving Cr-waste disposal
Hg	Chloralkali manufacturing Weapons production Copper and zinc smelting Gas line manometer spills Paint application Hg-waste disposal
Pb	Ferrous/nonferrous smelting Pb-acid battery breaking Ammunition production Leaded paint waste Pb-waste disposal Secondary metals production Waste oil recycling Firing ranges Ink manufacturing Mining Pb-acid battery manufacturing Leaded glass production Tetraethyl Pb production Chemical manufacturing

are listed below. Underlined technologies have been implemented (not necessarily in all applicable modes—ex situ, in situ, off-site, and onsite) on numerous metal-contaminated soils and are available from a substantial number of vendors. Bracketed technologies have been operated or demonstrated on metal-contaminated soil with some success at full scale on one to approximately five soils, and some cost and performance data are available. In situ horizontal barriers are difficult to implement but are included to address in situ containment options for all contaminated soil deposit surfaces. The remaining technology, electrokinetics, has been implemented at full-scale in Europe and not in the U.S. but is undergoing a Superfund Innovative Technology Evaluation (SITE) demonstration. As noted above, electrokinetics is not addressed in the bulletin. Other technologies (e.g., phytoremediation and bacterial remediation) are being evaluated and may provide low-cost remediation for low concentration, large volume wastes, but these technologies are not addressed here due to their early stage of development and application to metal-contaminated soils.

Technology Class	Specific Technology
Containment	<u>Caps, Vertical Barriers,</u> Horizontal Barriers
Solidification/ Stabilization	<u>Cement-Based</u> [Polymer Microencapsulation] [Vitrification]
Separation/ Concentration	[Soil Washing] [Soil Flushing (In Situ Only)] [Pyrometallurgy] Electrokinetics (Addressed in TRD only)

For each technology listed above, the following topics are discussed:

- Process description
- Site requirements for technology implementation
- Applicability
- Performance in treating metals in soil and Best Demonstrated Available Technology (BDAT) status
- Technologies in the SITE Demonstration Program
- EPA contact for the technology

The BDAT status of the technology (see fourth bullet above) refers to the determination under the RCRA of the BDAT for various industry-generated hazardous wastes that contain the metals of interest. Whether the characteristics of a Superfund metal-contaminated soil (or fractions derived from it) are similar enough to the RCRA waste to justify serious evaluation of the BDAT for a specific Superfund soil must be made on a site specific basis. Other limitations relevant to BDATs include (1) the regulatory basis for BDAT standards focus BDATs on proven, commercially available technologies at the time of the BDAT determination, (2) a BDAT may be identified, but that does not necessarily preclude the use of other technologies, and (3) a technology identified as BDAT may not necessarily be the current technology of choice in the RCRA hazardous waste treatment industry.

The EPA's SITE program (referred to in the fifth bullet above) evaluates many emerging and demonstrated technologies in order to promote the development and use of innovative technologies to clean up Superfund sites across the country. The major focus of SITE is the Demonstration Program, which is designed to provide engineering and cost data for selected technologies.

Cost is not discussed in each technology narrative; however, a summary table is provided at the end of the technology

tion of the total metals cleanup goals, one can see that they vary considerably both within the same metal and between metals. Similar variation is observed in the actual or potential leachate goals. The observed variation in cleanup goals has at least two implications with regard to technology alternative evaluation and selection. First, the importance of identifying the target metal(s), contaminant state (leachable vs. total metal), the specific type of test and conditions, and the numerical cleanup goals early in the remedy evaluation process is made apparent. Depending on which cleanup goal is selected, the required removal or leachate reduction efficiency of the overall remediation can vary by several orders of magnitude. Second, the degree of variation in goals both within and between the metals, plus the many factors that affect mobility of the metals (discussed earlier in the bulletin), suggest that generalizations about effectiveness of a technology for meeting total or leachable treatment goals should be viewed with some caution.

Technologies for Containment and Remediation of As, Cd, Cr, Hg, and Pb in Soils

Technologies potentially applicable to the remediation of soils contaminated with the five metals or their inorganic compounds